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Rapid Generation of Conceptual and Preliminary Design Aerodynamic Data by a Computer Aided Process

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ABSTRACT

A multidisciplinary integration framework (MIDAS- an acronym for Multidisciplinary Integration for Design and Analysis Software) is developed for a quick and accurate assessment of aircraft performance. The system allows for the continuos integration of the conceptual and preliminary design stages. The MIDAS system is starting from the definition of the configuration layout to provide basic aerodynamic data- for performance analysis, sizing, structural layout and early handling qualities. The first aerodynamic dataset is provided by an Excel-based module in a highly automated way. This data base can be updated by computational and experimental fluid dynamics findings. Another MIDAS module integrate the preparation of CFD meshes. The paper deals with the integration of aerodynamic methods within the aircraft design.

INTRODUCTION

Within the frame of a series of initiatives aimed at improving effectiveness of its aircraft design and analysis capabilities, the Military Division of DaimlerChrysler Aerospace AG (Dasa) is developing MIDAS, a multidisciplinary integration framework for aircraft design process. MIDAS targets specifically configuration studies in a conceptual and preliminary design environment, where peculiar requirements such as flexibility and robustness of the system components, reliability of results, user friendliness, and fast response times have to be properly addressed. The overall objective here is to reduce response times of analysis and iterative design cycles of one order of magnitude while increasing design quality and decreasing design uncertainties. The basic approach selected consists of cross-linking methodologies and numerical simulation tools already existing in the specific disciplines across a common interface, streamlining the data flow between the different building blocks by standardization of exchange data structures and creation of common data bases. In this paper the generation and integration of the aerodynamic data within the MIDAS system is presented.

INTEGRATION OF AERODYNAMICS IN THE DESIGN PROCESS

In the conceptual design phase, mission performance, trajectory optimizations, sizing, and stability and control require generation of a proper longitudinal aerodynamic data set. The aerodynamic data typically are presented as function or in tabular form, **Figure. 1**.

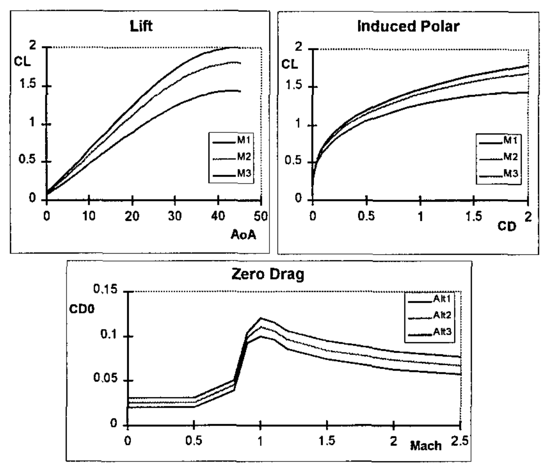

Figure 1 – Example of a [Trimmed] Aerodynamic Data Set as used for Point Performance Calculations

In general, the predicted aerodynamic data are derived from different sources. At the very beginning of the conceptual design loop, prediction of aerodynamic characteristics relies on handbook methods, existing databases, approximate methods, and correlation methodologies, often blended with sensible 'guess-estimated' values. Due to obvious limitations of this methodology, especially when applied to innovative – i.e. not evolutionary - designs, application of numerical methods of Computational Fluid Dynamics (CFD) can be beneficially used to improve the estimated aerodynamics as the design evolves into the preliminary design phase. To this purpose, numerical flow solvers of different degree of flow modelling fidelity are nowadays available, ranging from panel methods for prediction of linear flow characteristics to Euler flow solvers for assessment of non-linear aerodynamics – e.g. transonic flow and high-angle of attack characteristics, and Navier-Stokes solvers for viscous flow conditions. CFD and wind tunnel experiments are used to validate the aerodynamic design and to assess the risks for the following phase of the project.

An important feature of MIDAS is the inclusion of high fidelity numerical simulation methods in the early design process.

When applying CFD methodology, rapid and efficient ways to set-up the numerical models, run the flow simulations, analyze the results and extract the desired information must be devised for containing the required time and human

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efforts within values affordable and acceptable to conceptual and preliminary design project timeframes and budgets. Extrapolation of the progress in computing power of the last years let expect application of high fidelity CFD methods become the primary aerodynamic tool in the near future, but currently their use has to be limited to the analysis of critical flow conditions. Thus, since today CFD calculations do not cover the entire flight envelope of interest, predictions of different accuracy level have to be matched and balanced carefully. The generation of a consistent aerodynamic data set from the 'raw' aerodynamic data is a process which certainly requires sound engineering experience and may still involve time-consuming manual work, representing a severe bottle-neck within the entire design process chain.

In the following, the basic approach taken to overcome the present limitations and allow MIDAS 'open the way' to CFD methodology in conceptual and preliminary design analysis is presented and discussed.

BUILD UP OF THE AERODYNAMIC DATA SET

In a first development step, the MIDAS building blocks necessary to realize the coupling between configuration layout, aerodynamics, propulsion and masses – left side of Figure 2 - have been developed, ref. [1].

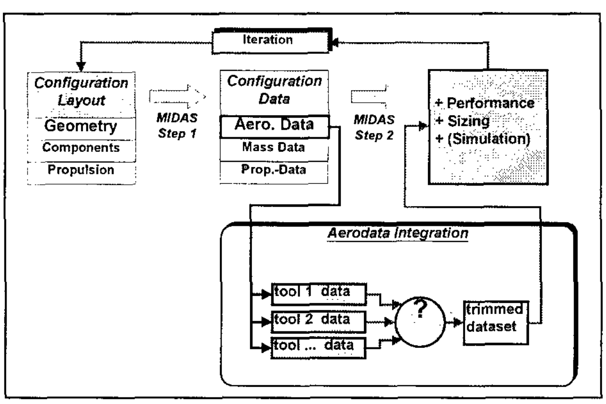


Figure 2: A/C Conceptual Design Iteration Principle and MIDAS Steps 1 & 2

In the second development step of MIDAS, an interactive build-up procedure for integrating the aerodynamic data and yielding the trimmed data-set required as input for operating the performance, sizing and flight simulation modules has been implemented. The position and the function of the aerodynamic integration module within the iterative design process is indicated by a question mark in the circle of the lower box in Figure 2.

The design and implementation of this aerodynamic integration module have been mainly driven from the specific functional requirements deriving from applications at Dasa conceptual design environment. Some of the main 'drivers' are presented here.

Unlike design of conventional transport aircraft systems, design of advanced military configurations may rely on a variety of different or novel arrangements of aerodynamic means for aerodynamic control and maneuvers. This in turn implies a high flexibility in the tool used for building up the aerodynamic set, which should be able to accommodate a broad variety of application rules.

Another requirement stems from the necessity to progressively refine and adjust the data set, as new information and more accurate data are becoming available during the design process. One common method to generate the initial aerodynamic data set is to provide the derivatives and the zero values for lift, drag and pitch moment coefficients integration of the functions by assuming some appropriate blending interpolation between the given data yields generally smooth functions, which can be used as first guess for performance and sizing calculations, Figure 3. These 'initial' curves are later adjusted as more accurate results – such as CFD calculations and wind tunnel experiments data – become available later, Figure 3.

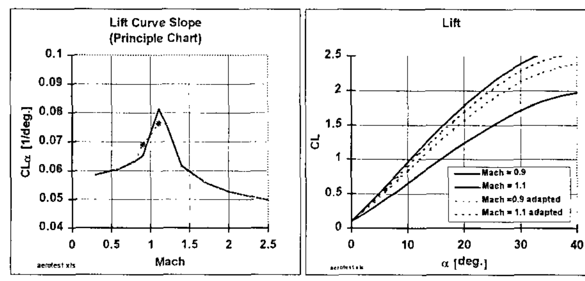


Figure 3: Example of Data set Adaptation Using Derivative Representation of Aerodynamic Data

The left hand side of the figure shows a preliminary crude derivative function and the right hand side contains the integrated coefficient. As an example, two adaptations are sketched as dots (left diagram) and the corresponding adapted curves as dashed curves (right diagram). In the same way fast variations and scaling of the data set can be performed.

With respect to trim, two different procedures are available. Initially, some 'educated-guess' of trim effects are added to the clean aerodynamic data. These trim losses are dependent on the stability characteristics of the configuration and on the zero pitching moment. Hence they can be neglected to the first order for configurations which are aerodynamically marginally stable and at design conditions. Later, initial assumptions must be refined by performing a trim calculation, by balancing all pitching moment contributions with respect to the actual center of gravity position. The effort in this case is clearly unlike higher but the trim losses can be determined with higher accuracy. In addition, better knowledge on the configuration become available, like required control power, control surface deflection settings and static stability margin.

An important feature for the integration module is the compatibility of the data set build-up procedure with the one incorporated in the Aero Data Module (ADM), a Dasa proprietary software tool used at the pre-design level, Ref. [2]. ADM contains and interpolates a complete 6 degree-of-freedom aerodynamic data set, which includes all control elements of an aircraft, and is used in flight mechanics and flight simulation. Output options of ADM in combination with the AERO-Module are clean and/or trimmed dataset or only parts of the dataset, gradient matrices and others **(Figure 4)**.

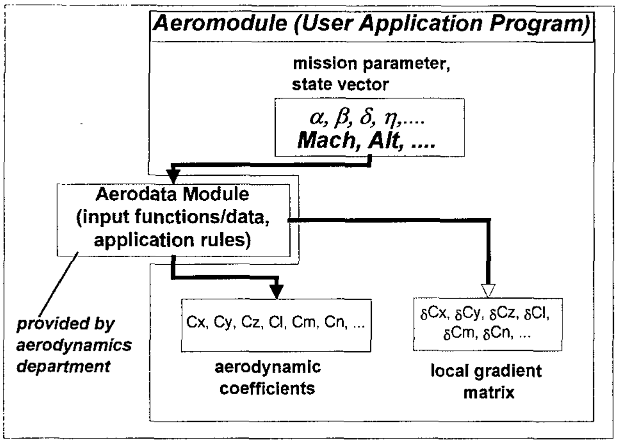


Figure 4: ADM and AeroModule (6 –DOF /11/)

The required compatibility with ADM allows to obtain a tight integration of the conceptual with the preliminary design phase, since the data sets established in conceptual design to be taken over in a later pre-design phase in terms of data and/or application rules.

QuADBUS Basic Layout Features

According to the set requirements, a software tool called QuADBUS -**Qu**ick **A**ero **D**ata **B**uild **U**p **S**ystem- has been developed. The overall integration of QuADBUS within the aerodynamic data set generation procedure for the conceptual design is sketched in **Figure 5**.

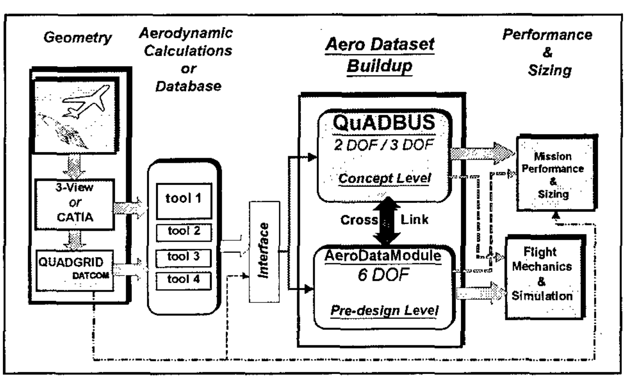


Figure 5: Flowchart of Aerodynamic Dataset Generation

This scheme shows that the data: flow can either incorporate the QuADBUS or the ADM (Aero Data Module) software tools (QuADBUS is used at the *conceptual design level*, whereas ADM serves for the *pre-design level*).

Unlike ADM – which consists of a series of FORTRAN library that must be linked together with the specific application program - QuADBUS is implemented as an EXCEL-based standalone application. Using the de-facto standard EXCEL spreadsheet environment, the user can perform the data manipulations using the EXCEL interactive cell operations, while visually controlling the effect of the data alterations – in real time – using the EXCEL-built-in graphic capabilities. Plug-ins to specific macro functions written in VisualBasic allow the execution of calculation tasks (e.g. interpolation, gradient computation, solution of linear systems, appliaction rules). Although the computational speed of the Excel implementation is several orders of magnitude more slowly compared to an equivalent implementation in FORTRAN, no appreciable drawback has been perceived so far. For an application using a calculation matrix of following dimensions:

Variable Type	No of Variables
Mach number	15
Angle of Attack	20
1st Control Surface (Preset)	15
2nd Control Surface (Trim Element)	10
Altitude	10

and requiring the usage of about ten Visual Basic routines in the background, a PENTIUM II-233 processor takes about 10 seconds for the entire calculation process with trimming and update of all graphs. The associated size of the Excel file is 4.5 Mbyte.

QuADBUS Internal Dataflow and Module Arrangement

The required flexibility in building up the data set using a broad variety of application rules is obtained combining the spreadsheet feature of the EXCEL software itself with the VisualBasic capability to realize calculation program modules.. **Figure 6** illustrates schematically the migration of the data within QuADBUS from the definition of the input data for the clean configuration (left side) to the output of the trimmed data for the complete configuration.

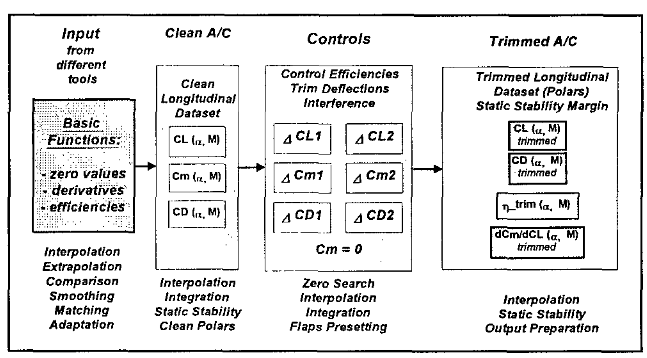


Figure 6: QuADBUS Principle Dataflow

The parts relevant to the controls (input data and associated application rules) are always present but become inactive for those components that have not been explicitly defined. The application rules used for the coefficients build-up are defined as VisualBasic functions in separate files.

The user interface used to communicate with the internal data flow structure is represented by an EXCEL template, **Figure 7**: The workfile contains several worksheets (for geometry, mission, input functions, clean configuration aerodynamics, ...) and VisualBasic sheets with the routines

as necessary e.g. for the application rules and for the trim calculation.

Separate input sheets include groups the input data which are read in by an EXCEL macro or which may be copied from an ASCII file. The same kind of presentation – tables, graphs - are realized for the output of the calculated datasets.

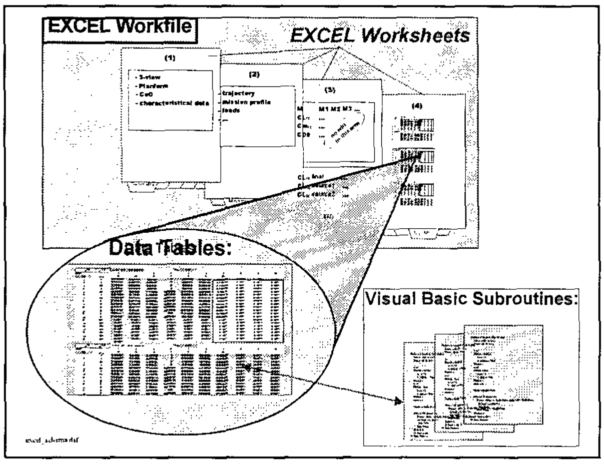


Figure 7: QuADBUS User Interface (EXCEL Workfile)

For the build-up of a new configuration aero dataset, first a copy of the QuADBUS *master file* must be opened and filled with the data of the actual configuration under concern. At the beginning, the cells relevant to the input are empty. The worksheets are marked for the various inputs and in addition are prepared for the dataset build-up process. The user can either type or copy the data into the tables, from an existing data set or from plain ASCII files as available, and can watch the dataset growing. As navigational aids, cells eligible to receive user's input are highlighted with different colors, depending whether the input is necessary or optional. All remaining cells, where intermediate and final results are stored, are write-protected in order to prevent accidental modification or deletion.

The calculations can be performed either step-wise, sheet-wise or for the entire workfile. Data generally may be changed by editing of the single cells and/or by drag-and-drop mouse operation in the graphs.

Application Rules Handling

Internally in QuADBUS, each aerodynamic coefficient is represented by a sum of additive terms, whereas the application rules specify how these terms are combined together in dependency of the independent variables, e.g. Mach number, altitude, angle-of-attack, control settings. For example, the lift and drag curves for the clean configuration are defined using the zero-values, linear slopes, non-linear terms, minimum and maximum values, interference and flow separation dependent terms, resulting in the final lift curve shape and drag polars, as shown in **Figure 8**.

This decomposition mechanism allows to separate the effect of each particular influence parameter on the global curves, a useful feature in conceptual design, where estimated values for these parameters can be assumed to be dependent from the geometrical characteristics of the configuration by means of semi-empirical formulas (like e.g. body influence on wing planform efficiency, wing leading edge suction, vortex lift) .

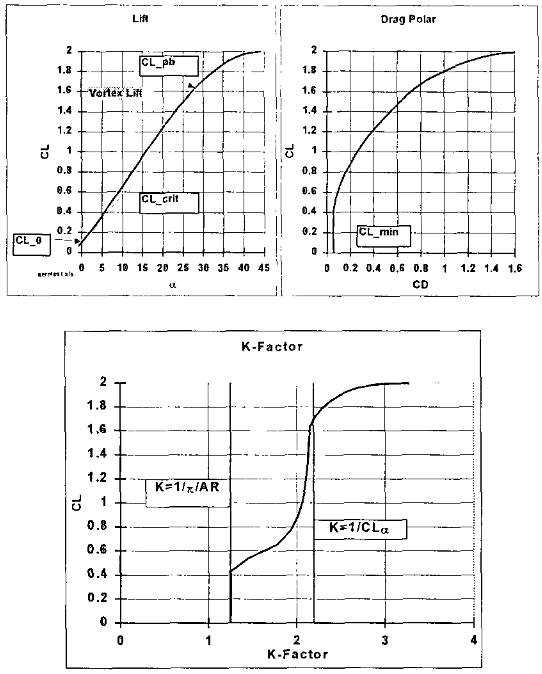


Figure 8: Elements of Lift and Drag Build-up of the clean A/C

To this purpose, a limited geometry description and analysis capability is optionally available in QuADBUS, which allows to extract automatically the geometrical parameters relevant for the aero data build-up process (e.g. wing planform, surface area, mean aerodynamic chord, control volumes, cross-section area distributions.) from a schematic three view layout of the configuration, **Figure 9**.

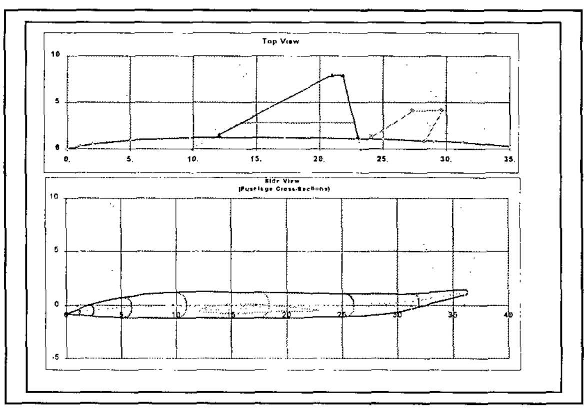


Figure 9: Planform and Cross-Section Input Options

In this way, the total lift curve may be obtained by adding non-linear contributions from leading edge and tip vortices computed according to DATCOM /12/, Schemenski /13/, Polhamus /14/ relations. The non-linear lift contribution of low aspect ratio wings, e.g. can be described as $CLv = Fv\ (1\text{-}R)\ Kv \sin^2\alpha \cos\alpha$ where Kv is a function of the LE and TE sweep angles and Mach number, and Fv is a vortex breakdown factor vs. aspect ratio and angle of attack, **Figure10**.

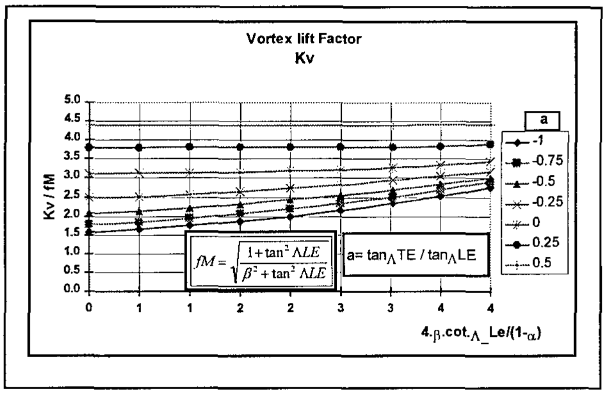


Figure 10: QuADBUS: Vortex Lift Factor Dependency

The leading edge suction parameter R of course is depending on the profile of the wing, the angle-of-attack and the aspect ratio. In QuADBUS parameters and factors like the above described ones can either be imported from outside or interpolated from the tables located in the background sheets of QuADBUS, using the geometry parameters as calculated from the geometry sheet.

In a similar way, the induced drag of the A/C is computed by a special procedure that allows a broad variety of manipulations, which take in account the real flow behaviour and still may be adapted to the data which are available to the user:

The strategy for the induced drag build-up within QuADBUS is sketched in **Figure 11**, where four options can be chosen by the user: As basic solution, the induced drag for the clean aircraft is automatically computed according to DATCOM/Schemensky methods /12, 13/ as a function of the Mach number and lift coefficient using the available geometrical information.

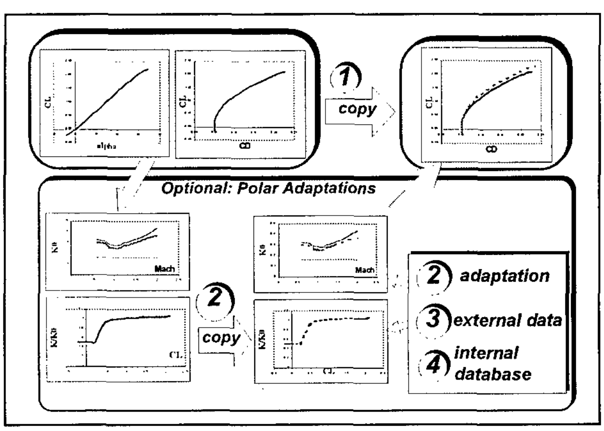


Figure 11: Options in Composition of Drag-Polars

1. *Implemented Procedure and/or*
2. *by Comparison of Similar A/C and Manipulation of K-Factor*
3. *Input of K-Factor Tables (external data)*
4. *Using internal database*

The first option consists of using directly this estimated polar in all further calculations ①.

For the other options, the basic polar is presented in the following parabolic fitting form:

$$\boxed{CDi = K0\,(Ma) \cdot K/K0\,(CL, Ma) \cdot (CL\text{-}CLmin)^2}$$

where the K0 and K factors depends on the Mach number and on both Mach and lift coefficient respectively. This kind of representation is – in fact – quite usual in conceptual design and allows an experienced user to make sensible educated-guess for the K-factor values when no better estimates are available. Hence the second option allows the user to operate directly on the K-factors tables, while verifying the effect of the adaptation on the induced polar curves(Figure 11). The third option allows to import K-factor tables or CDi tables from outside- e.g. produced by CFD calculations ③ and to start the polar calculation at this point.

The fourth option is using a QuADBUS internal database ④, where statistical values of typical K-factors are stored for different aircraft categories. **Figure 12** shows the upper and lower bounds of the stored K-factors for fighter type aircraft. The user is then required to define the actual curve he intends to use within the shown bandwith.

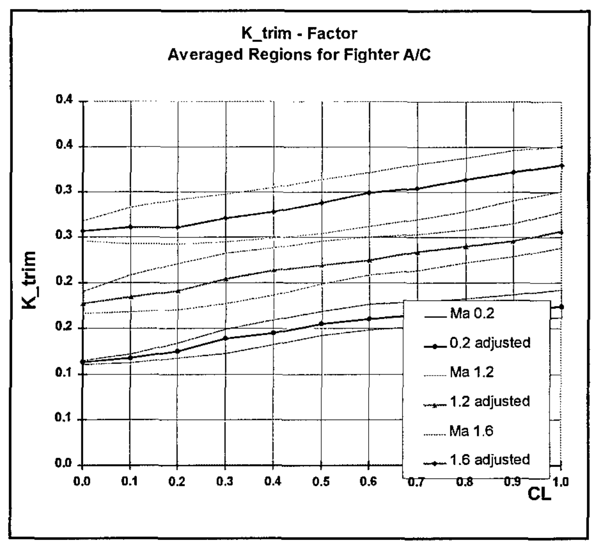


Figure 12: Example for using the K-Factor Database in QuADBUS (here: Combat Aircraft)

EXAMPLES OF APPLICATION

In the following two application examples are given for demonstrating the capability of the QuADBUS module.

QuADBUS Application Example 1: Clean Polar Buildup

An existing pre-design data set has been used as benchmark in an evaluation exercise aiming at assessing QuADBUS capability in the generation of the aerodynamic data set for an advanced fighter-type configuration. For simulating the operability conditions typical of a conceptual design phase, no other 'external' information but zero values and linear gradients have been used in QuADBUS. The reference

data set –generated by the ADM module – is based on CFD and wind tunnel data.

Figure 13 shows the comparison of lift and drag polars for a subsonic and a supersonic Mach number. As can be seen, QuADBUS predictions of non linear effects on both lift and induced drag compare well with the reference data.

The effort required to operate QuADBUS for generating the data is orders of magnitude lower compared to ADM operation.

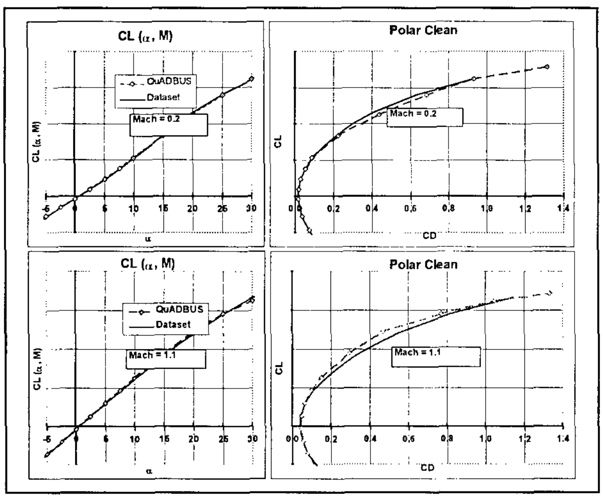


Figure 13: Comparison of Original Dataset (Generic Combat Aircraft, Experimental & CFD Data) and QuADBUS Integration Procedure Results

QuADBUS Application Example 2:Trim Calculation for Two Different Center of Gravity Positions

In this application, the trim capability of QuADBUS is used to investigate the aerodynamic variations due a rearward shift of the configuration center of gravity.

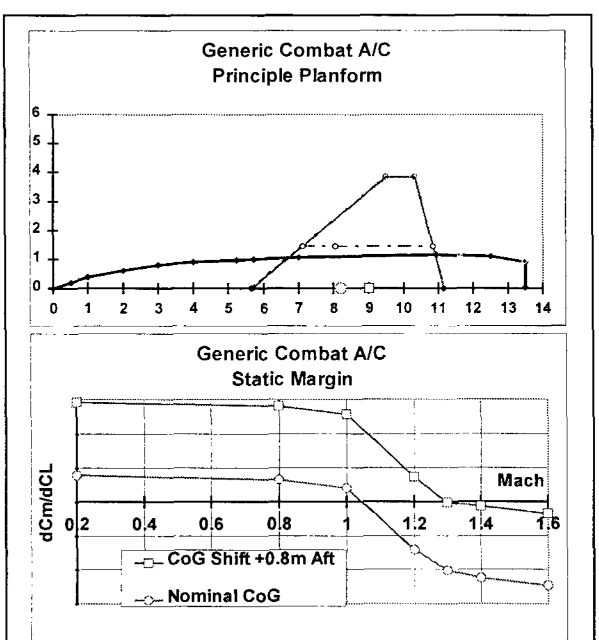


Figure 14a Generic Combat Aircraft Planform and: Static Margin Stability

.**Figure 14** .shows the planform of the configuration and the two center-of-gravity positions used in this example. The lower part of Fig.14a contains the resulting static stability margin vs. Mach for the two CoG positions, as calculated by QuADBUS.

A selection of typical output graphs from QuADBUS, the aerodynamic performance L/D_trim, and the corresponding elevator trim angle δ_trim is presented in Fig. 22b (nominal CoG position) and Fig.14c (rearward shifted CoG position). The wing trailing edge flap schedule for this example was (M=0.3: η_TE = 10°; M=0.9: η_TE = 5°,; M>1: η_TE = 0°).

From Figure 14c it can be seen that for M=0.2 the curve for the trim angle of the elevator reaches saturation at an angle of attack 20. The variations illustrated in Figure 14 are performed in less than half a minute, including all graphs, (not shown here; related to that example, about 150 graphs in the background were active for control purposes). The user interaction is limited to update the x-position of the center of gravity in one cell.

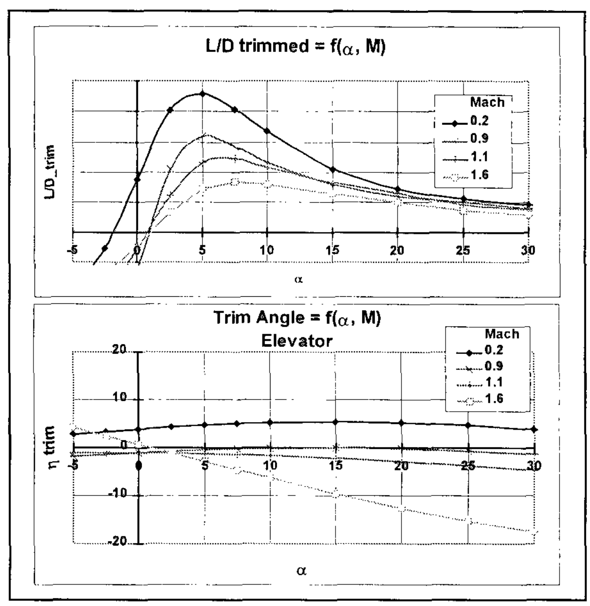


Figure 14b: Trim Results for nominal X_CoG

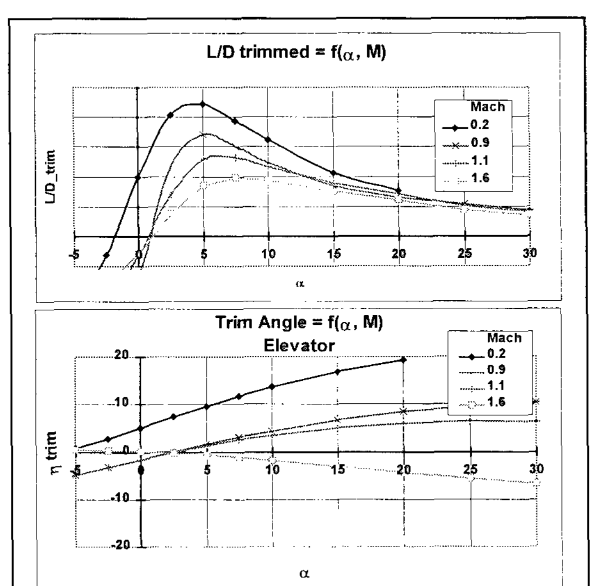


Figure 14c Trim Results for rearward X _CoG (+ Δ0.8m)

RAPID SURFACE MESH GENERATION

Presently the HISSS panel method – **Ref. 6** and AIRPLANE+ -an in-house development of the AIRPLANE Euler unstructured flow solver of **Ref. 7-8-10** - are integrated in MIDAS. The mesh generator FLITE – **Ref 9** – is used to generate the unstructured volume grid used by the Euler solver. Both the panel method and the unstructured mesh generator require as geometry input the definition of a structured surface grid. The generation of a valid surface mesh about a complex aircraft configuration is a demanding task, which requires considerable amount of skill and effort, **Figure 15**.

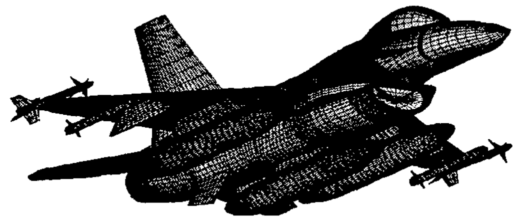


Figure 15 – Surface panelling for a F16-type Fighter Aircraft -

At the very beginning of a conceptual study a complete lofting model does not exist, therefore a simplified geometry definition is integrated in MIDAS. To this purpose, the geometry generator PGRID has been developed, that allows to obtain a valid surface model in a highly automatic way from a limited amount of geometrical data. The surface model generated by PGRID can be directly used as input to the panel method and/or to the unstructured mesh generation.

Later in the design stages, it is desirable to start the grid generation process from a high-quality CAD model, that is the repository of geometrical layout of the configuration during the design phase. Since CAD models are normally defined for constructive purposes, they are normally not readily suitable for mesh generation. Filtering and uncluttering of superfluous elements, restoration of surface integrity by closure of gaps and removal of overlap, modification of badly meshable regions are required before the meshing process can start. When done manually, this preparation activity may take several labour weeks. In the ESPRIT Project JULIUS a CAD Repair tool is being specifically developed to reduce substantially the effort of extracting a 'ready-to-mesh' surface model from a 'dirty' CAD model.

The two tools are briefly presented in the next setions.

The Geometry Generator PGRID

The lofting strategy adopted in PGRID – Parametric Geometry by Reduced Input Data - focusses on typical aeronautical applications, without any claim to generality, and combines different elements from existing approaches, **Ref.s 3-4.** The basic idea is to reduce the amount of information required to define an airplane geometry by decomposing the whole configuration into a set of isolated parts, like fuselage, wings, tails,. and letting the geometry generator itself performing all the operations necessary to yield a geometrical model satisfying the surface mesh generation requirements (i.e. surface continuity, closed-volume domains).

The whole configuration is broken down into its constructive parts, i.e. fuselage, engine inlet and outlet or nacelle, wings, control surfaces, external pods. Each of these components are defined and modeled in isolation, and subdividing it into a set of geometrically less complex surface elements (patches). The three-dimensional surface of each patch is then described by bi-dimensional parametric polynomial functions. The actual shaping of these parametric surface is controlled by the user via specification of a set of variables. Three different types of surface specification are available:

Body-like component patches are described by defining the evolution of a conic curve between two opposite boundary curves by means of blending functions. 4th-order parametric polynomial functions after –**Ref.4** - are used for both the conic and the blending curves;

Wing-like component patches are defined by assuming a linear variation between two wing sections arbitrarily positioned in space. A database of over 200 different wing sections is directly accessible from the program; if necessary, the profile thickness can be scaled to the user specified value;

B-Splines surface patches can be used indifferently to describe body- or wing-like components; they are defined starting from a rectangular array of grid points and using a least-square deviation procedure to determine the set of control points which 'best-fit' the given points; once computed, the B-spline parameters - i.e. control points and parametrical vectorbase, /4/ are stored in IGES format into a local database for later use; a similar technique is followed for determining and storing b-splines curves used for interpolating airfoils section originally available in tabular form;

Starting from the individual specification of the configurations components the grid generator performs automatically a series of operations, which, requiring only a few additional user's directives allow to yield a 'valid' a surface mesh:

Definition of the initial mesh: according to the user's specifications, each patch is discretised into a rectangular **mxn** array of points - i.e. a certain number **n** of sections each carrying **m** points; the location of the inner points is found from the given point distribution along the boundaries by applying a Laplace solver in the parametric space;

Generation of connectivity relationships: a topology information table is automatically built to keep trace of the connectivity relationships of each patch to its neighbors; all

patches connected together are stored into a special data structure called *thread*; depending along which boundary curve the patches are connected a distinction is made between m- and n-threads; in order to satisfy the contiguity meshing requirements the number and the location of the points along the edges shared by two patches must be identical; as a general rule, the number of points for each patch is raised to the largest dimension found in the local threads;

Calculation and regridding of part intersections: curves between two intersecting parts are discretised by calculating the piercing points between the curves of one part - defined as *master* - and the surface of the other part - defined the *slave* - ; hence, 'master' parts retain their original topology, while slaves parts must be re-gridded in order to fit the intersection curves; again the points on the slave patches are redistributed by using the Laplace smoother in the parametric space. In general, master patches retain their original number of points, unless the case when one or more slaves are intersected by topologically independent masters - e.g. short-coupled wing-foreplane.

Final regridding and validity check: After having intersected all compenetrating parts, fulfillment of the contiguity condition is checked again and, when necessary, gridding of patches with insufficient number of points is updated. Then a check is performed breaking up contiguous boundary curves into identical *segments*: a necessary condition for a 'valid' mesh is that each segment must bound exactly two patches or - for symmetrical configurations, one patch and lie on the symmetry plane.

Application to a Business Jet Aircraft

The generation of a surface mesh for a typical business-jet configuration is presented. The general layout of the configuration has been derived from the GULFSTREAM IV three-views drawing from /4/.

Figure 16a shows the build up of the airplane configuration. The fuselage and the engine nacelle have been described using the body-like input form, while wing, winglets, wing/winglets fairing, horizontal and vertical tail, and engine pylon make use of the wing-like description scheme. The fuselage has been further subdivided into smaller parts, for achieving a better control of the cross section distribution The solid lines represents the patch boundary curves. For sake of simplicity the wing and the engine pylon has been extended up to the symmetry plane.

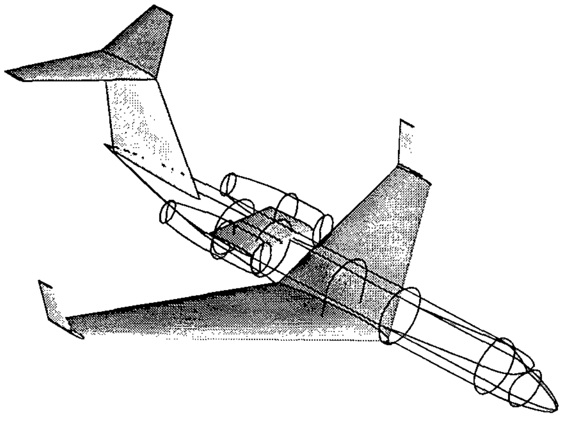


Figure 16 - Business Jet Configuration
(a) Schematic representation of user defined input

The Figure 16b represents the grid of the central part of the fuselage after the calculation of the intersections with the wing and the engine pylon. The patch boundaries are rendered by thicker solid lines. The two blank areas represent the footprints of the innermost sections of the wing and of the pylon. Aiming at obtaining a smooth transition from the wing to the fuselage grid lines, a special user's directive has been used to wrap the body grid around the wing leading edge - the so-called C-type topology option. An H-topology type intersection has been produced at the pylon intersection (default topology).

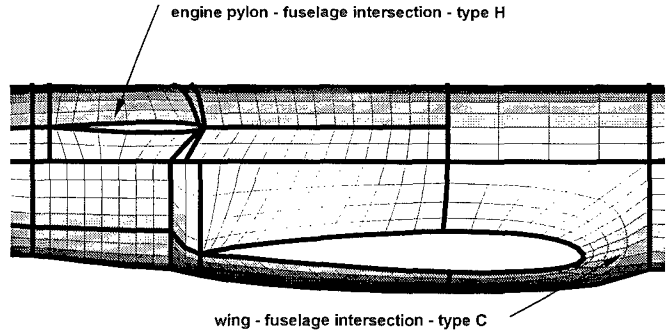


Figure 16 (b) Intersection regions on fuselage

Due to local topological constraints, the number of chordwise points of the pylon have been automatically decreased from its original value.

The appearance of the final surface grid for the complete configuration is rendered in figure 16c. The topology information are used to obtain a 'closed- volume', contiguous grid.

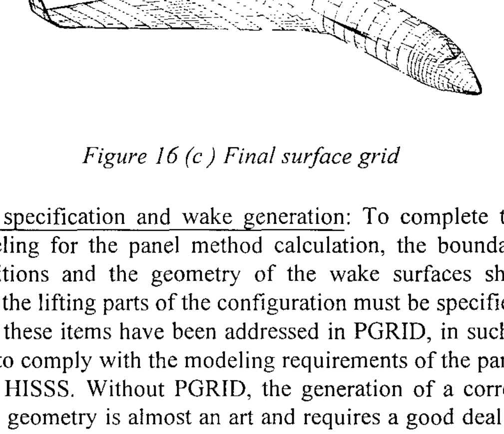


Figure 16 (c) Final surface grid

B.C. specification and wake generation: To complete the modeling for the panel method calculation, the boundary conditions and the geometry of the wake surfaces shed from the lifting parts of the configuration must be specified. Both these items have been addressed in PGRID, in such a way to comply with the modeling requirements of the panel code HISSS. Without PGRID, the generation of a correct wake geometry is almost an art and requires a good deal of practice. The approach followed here has been to transfer the expertise directly to the mesh generator, leaving to the user the task to check the validity of the automatically generated wakes, and providing him/her the possibility to

define or modify the wake modeling manually. Figure 16d, next page - presents the wakes generated in full automatic mode by PGRID for the GULFSTREAM configuration.

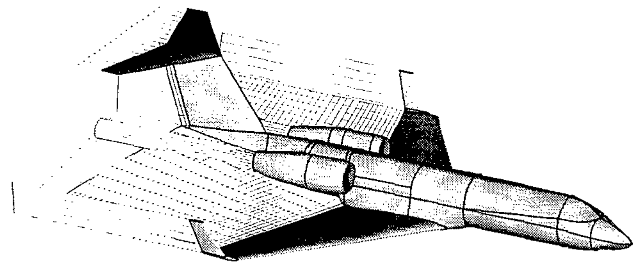


Figure 16 - Modelling of a Business-Jet Aircraft (d) automatic wake arrangement

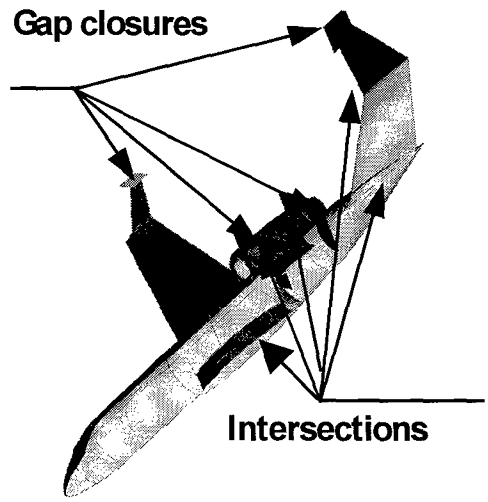
The GULFSTREAM modelling presented here has been computed in a couple of minutes on an intel 486 lap-top with only 8Mb RAM. The basic configuration input data have been defined by hand in two hours work back in 1995 as first application of PGRID to a complete wing-fuselage - tails and nacelle. The engine pylon has been introduced later for demonstrating the multiple intersection capability.

The JULIUS CADR Tool

In compliance with the technical requirements specified by end-user partners of the ESPRIT Project EP the Institute for Production Systems and Design, IPK, Berlin, is developing the interactive application software CADR – CAD Repair. The CADR tool integrates a commercial CAD translator which imports a CAD model from an IGES description and transforms the imported data into a NURBS-based data structure. Based on an analysis of these data, the topological information tree of the model is performed, that in turn, is used for detecting topological and geometrical errors of the models. Interactive commands or predefined operation sequence are used to obtain a 'waterproof' surface models that satisfies the requirements of the downstream application modules. At the end of the 'repairing' actions, all the geometrical and topological information are stored into a BREP+ data structure. The geometrical part of BREP+ structure is based on trimmed NURBS-patches. In cooperation with the partners CSCS and SMR, IPK is presently implementing the capability to detect 'badly'-meshable elements, as tiny faces, high aspect ratio elements. Merging of patches by reparametrisation and carpeting techniques are then used to improve the local mesh quality.

CADR Application: Business Jet Airplane

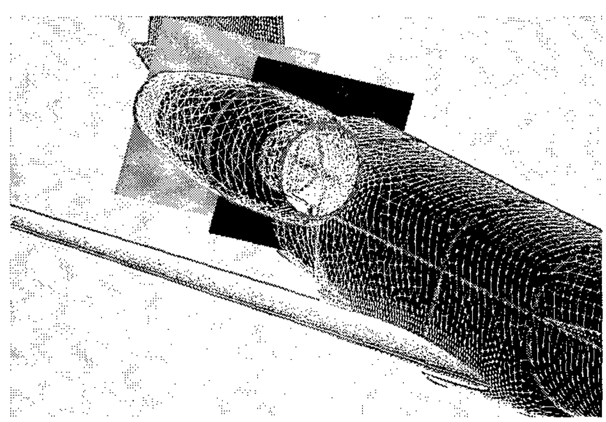
For sake of comparison, the aircraft configuration defined by PGRID is presented. The Business Jet geometry is imported in CADR using an IGES description of the surface patches of the isolated components, **Figure 16a**. Executing the default sequence of operation, CADR performs automatically following operations: splitting of folded surfaces, finding of common edges, calculation of intersecting curves, trimming of surfaces by edge curves, detection of gaps. At the end of the sequence, visualisation of patch attributes is used to help the user to remove the trimmed parts of the wing, tails and engine pylon parts falling inside the fuselage and the engine nacelle. Visualisation of the attribute 'gaps' allows to selectively pick the pairs of free edges eligible to be closed by automatic construction of proper surfaces that are added to



the data structure, **Figure 17.**

Figure 17 – CADR repairing operations

Running the verification sequence it can been verified that the model is now geometrically and topologically valid. The model can be now be stored into the BREP+ data structure. A FLITE-compatible file is written for the unstructured mesh generator. A detail of the surface triangulation obtained by FLITE is shown in **Figure 18**. By comparison with figure 16b it can be seen that the use of trimmed patches by the CADR module allows to avoid the segmentation of the original patches in the intersection regions, improving the quality of the local mesh. The CAD repair for this model takes less than half an hour for a user



with little specific experience.

Figure 18 – Detail of the unstructured surface mesh

CFD RESULTS

In this section some selected CFD results are presented. The whole process, from the definition of the geometrical models to the CFD computation has been carried out using the tools discussed in this paper.

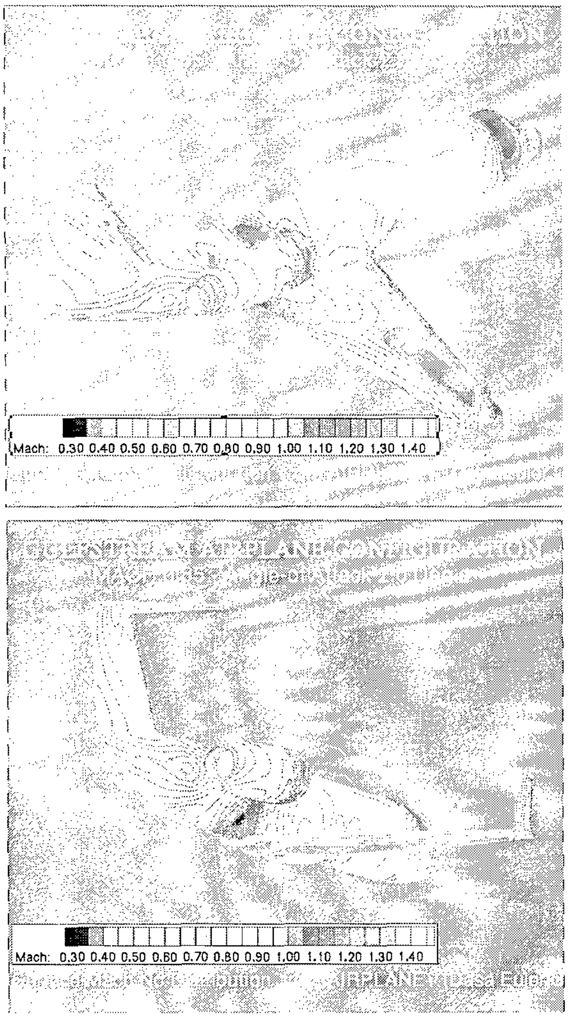


Figure 18 – Visualisation of AIRPLANE+ calculation

CONCLUSIONS

Integration of CFD methodology in the generation of the aerodynamic data set gives the opportunity to reduce design risks already in the earliest design studies. The system presented here allows to remove two bottle-necks in the application of CFD tools and to obtain accurate aerodynamic data already in the initial conceptual design phase.

A typical bottleneck within the conceptual design process is the integration of the aerodynamic results from the various tools and data sources into a consistent aerodynamic dataset. A software platform (QuADBUS) was developed to allow rapid build-up of the trimmed aerodynamic data set using interactive data manipulation. The system is suitable for execution of design variations/trade-offs calculations and of sensitivity analysis. The tool is based on commonly available spreadsheet software, allowing the user to work in an open, but well structured environment – comparable to the former engineering work using pencil, rubber and pocket calculator – but having the full digital support of modern information technology.

A new set of tools covering both the geometry definition and the mesh generation task has been developed for reducing the effort when generating computational meshes around complex airplane configurations. The applications presented here demonstrate the present capability and the potential of the proposed approach. Requiring a minimum of training and few more data than a three view layout to start with, the new system allows to generate within reasonable response times structured surface meshes about geometrically complex airplane configuration, thus allowing to promote the use of powerful CFD analysis tools in the conceptual and preliminary aircraft design.

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